VI. *On the Relation of the Air and Evaporation Temperatures to the Temperature of the Dew-Point, as determined by Mr.* Glaisher's *Hygrometrical Tables, founded on the Factors deduced from the six-hourly observations made at the Royal Observatory, Greenwich. By* John Fletcher Miller, *F.R.S., F.R.A.S., Assoc. Inst. C.E. &c. Communicated by Lieut.-Col.* Sabine, *For. Sec. R.S.*

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Remarks.

Of all the instruments observed and recorded by the meteorologist, the hygrometer is in many respects the most valuable, both in a scientific and practical point of view; for, by a simple knowledge of the point at which the atmosphere can contain no more vapour without precipitation at its existing temperature, and which is called the point of saturation or temperature of the dew-point, many other highly important collateral conditions, such as the elastic force of vapour, the weight of vapour in a cubic foot of air, and the additional weight required for complete saturation at all temperatures of the air, the relative degree of humidity, and the weight of a cubic foot of air under the ever-varying circumstances of heat, moisture and pressure, may readily be obtained, either by well-known formulæ, or by inspection from tables prepared for the purpose. But the hygrometer is also of no small value in the arts and in the practical concerns of life: as a prognosticator of the weather it stands second to no other instrument except the barometer, which it often rivals in the faithfulness of its movements; whilst the condition of the air as to moisture or dryness is acknowledged by all physicians to have no slight effect on the human body, both in its normal and abnormal state; but more especially are its influences visible on the frame of the invalid, either in aiding to restore healthy functions, or in promoting the exacerbation of disease.

It is therefore of no small moment that scientific observers, at least, should possess an instrument by which that important element, the dew-point, can be accurately and expeditiously obtained.

Dalton and other old meteorologists made use of glass vessels filled with spring water, which retains a nearly uniform temperature throughout the year; and, in the summer months, it was generally found sufficient to cause a deposit of moisture on the outside surface of the glass. In winter, ice or snow was mixed with the water, or when the temperature was very low, freezing mixtures were employed.

The dew was carefully wiped from the surface of the vessel as long as it continued

to form, and the moment it ceased, the temperature of the water was carefully noted and recorded as the existing dew-point.

This rough and tedious method has however long been superseded by the use of that beautiful and delicate apparatus bearing the name of the late Professor DANIELL, which gives the dew-point at once in degrees of FAHRENHEIT's scale. Highly valuable as this instrument unquestionably is, it is yet open to some objections, more especially in the hands of non-scientific persons.

1st. The reduction of the air temperature to that of the dew-point is effected by the rapid evaporation of sulphuric ether from a hollow ball of glass covered with fine muslin. Now ether is rather an expensive material, and it is essential that it should be unadulterated and of the strongest description, and such cannot always be obtained, even in large towns. An old established and respectable druggist tells me, that until recently (and the practice probably still exists in many places) it was the invariable custom of the trade to mix one part of spirits of wine with every two parts of ether. And I remember examining some ether in use by a young friend who professed to take hygrometrical observations with this instrument, which I should say contained a still larger proportion of alcohol in combination with *water*. This analysis of its composition is based on the fact that it might be used *ad libitum*, without depressing the temperature more than two or three degrees. Long experience has convinced me, that unless the evaporating fluid be pure, the results, if obtained at all, cannot be depended upon. The Ether rect. fort. should, if possible, be employed.

2nd. Some experience, great care and a quick eye, are requisite to secure accurate observations, and to catch the temperature at the exact moment when the annulus of dew begins to form on the dark bulb in the plane of the internal liquid surface.

3rd. If the ether be dropped on the bulb too quickly, too high a dew-point will be obtained. The ether phial should be fitted with a small siphon, and the heat communicated to the fluid by the hand will be sufficient to force it out slowly in drops.

4th. The atmosphere may be so exceedingly dry, particularly in the months of April and May, that no quantity of ether, even of the best kind, will suffice to reduce the temperature to the point of saturation. And this is more especially the case in warm climates, where this fluid deteriorates most rapidly by keeping. At sea, in tropical latitudes, I have sometimes been unable to find the dew-point with DANIELL's instrument for two or three consecutive days.

Such instances are however rare in this country; when they occur, freezing mixtures must be had recourse to, but I have very seldom had occasion to use them. The greatest difference I have ever observed between the temperature of the air and the dew-point, was 28°, on the 27th of April, 1842. The highest dew-point I have recorded was 68°, on the 17th of August, 1843, with 7·53 grs. of vapour in a cubic foot; the lowest was 8°, on the 14th of February in the same year, the air temperature being 26°, and the weight of vapour in a cubic foot only 0·87 gr.

The dry- and wet-bulb thermometers, as a means of obtaining the dew-point, did

not come into use until many years after the invention of Daniell's instrument, and from the want of correct tables, based on an accurate knowledge of the relation existing between the air and evaporation temperatures and the temperature of the dew-point, they were, until recently, of comparatively little service to the scientific observer.

When the magnetic and meteorological observatory was, at the suggestion of the Royal Society, established at Greenwich, two-hourly observations of the dry- and wet-bulb thermometers began to be taken, whilst the dew-point from Daniell's hygrometer was recorded every six hours, simultaneously with the temperature of the dry and wet bulbs; and these readings have been continued up to the present time. Such frequent observations, made by careful and competent observers with the best instruments, could not fail in time to afford the requisite data for the computation of an empirical dew-point, at all known temperatures of the air. The volume of Greenwich Magnetical and Meteorological Observations (copies of which the Astronomer Royal is kind enough to send me) for 1843, contains a complete discussion of the results down to 1845, from which the following factors were deduced:—

When the temperature of the air is	below 24°	the difference between the temperature of evaporation and the temperature of the air multiplied by	8°·5	gives the difference between the temperature of the air and the temperature of the dew-point.
Between	24° and 25°	„	7°·3	„
Between	25 and 26	„	6·4	„
Between	26 and 27	„	6·1	„
Between	27 and 28	„	5·9	„
Between	28 and 29	„	5·7	„
Between	29 and 30	„	5·0	„
Between	30 and 31	„	4·6	„
Between	31 and 32	„	3·6	„
Between	32 and 33	„	3·1	„
Between	33 and 34	„	2·8	„
Between	34 and 35	„	2·6	„
Between	35 and 40	„	2·5	„
Between	40 and 45	„	2·3	„
Between	45 and 50	„	2·1	„
Between	50 and 55	„	2·0	„
Between	55 and 60	„	1·8	„
Between	60 and 65	„	1·8	„
Between	65 and 70	„	1·7	„
	above 70	„	1·5	„

From these data, Mr. Glaisher, of the Royal Observatory, in the year 1847, cal-

culated, arranged and printed, at his own cost, an elaborate series of tables, showing, at a glance, the relation of the *temperature of evaporation* to that of the dew-point at every degree of the air temperature, from 10° to 90°; also the elastic force of vapour, weight of vapour in a cubic foot, the remaining quantity required for complete saturation, the relative degree of humidity, and the weight in grains of a cubic foot of air, under the varying conditions of heat, of humidity and of pressure.

Notwithstanding a conviction of the accuracy of Mr. GLAISHER's tables, both from the well-known character of the chief observer and compiler, and the favourable circumstances under which the elements were obtained, yet having found similar tables defective, and having used DANIELL's apparatus with satisfaction for many years, I felt reluctant to abandon it for the wet- and dry-bulb thermometers, slight as is the trouble of observing them, without personal experience of the correctness of the tables by which the dew-point was to be eliminated.

Accordingly, I sent up my DANIELL's hygrometer to Greenwich for comparison with the observatory standard thermometer, and, at the same time, Mr. GLAISHER kindly procured me a pair of delicate thermometers on the same metal frame, selected from a number of others, and made by BARROW of Oxenden Street. These thermometers were considered to have identical readings under similar circumstances, and both to agree with the Greenwich standard. The dew-point thermometer was also found to be generally correct, the errors mostly amounting to small fractions of a degree.

With these instruments the observations embodied in the annexed Tables were made in the years 1847 and 1848, the hours of observing being 11 o'clock in the morning, and 3 o'clock in the afternoon.

Hygrometrical state of the Atmosphere at Whitehaven, in the year 1847.

1847.	Dry bulb.			Wet bulb.			Dew-point.								
							Deduced.			Observed.					
	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	Compt. of dew-point.		
													11 A.M.	3 P.M.	Mean.
January	36°·64	38°·61	37°·62	°	°	°	°	°	°	32°·50	33°·82	33°·16	4°·14	4°·79	4°·46
February	37·17	39·64	38·40	......	......	......	......	......	......	31·14	32·10	31·62	6·03	7·54	6·78
March	43·13	46·34	44·88	......	......	......	......	......	......	36·03	36·09	36·06	7·10	10·25	8·82
April	45·68	47·75	46·71	......	......	......	......	......	......	38·55	39·53	39·04	7·13	8·22	7·67
May	55·70	57·23	56·46	51·46	52·82	52·14	48·40	49·50	48·95	47·96	49·25	48·60	7·74	7·98	7·86
June	59·85	61·75	60·80	54·96	55·63	55·29	51·50	51·00	51·25	51·43	50·98	51·20	8·42	10·77	9·60
July	64·98	67·46	66·22	59·96	61·36	60·66	57·00	57·80	57·40	57·11	57·66	57·38	7·87	9·80	8·84
August	61·53	62·70	62·11	56·87	57·56	57·21	53·90	53·78	53·84	53·95	53·78	53·86	7·58	8·92	8·25
September	55·03	56·26	55·64	50·96	51·11	51·03	48·20	47·30	47·75	47·82	46·68	47·25	7·21	9·58	8·39
October	54·09	53·82	53·95	50·88	50·37	50·62	48·20	46·80	47·50	48·02	47·04	47·53	6·07	6·78	6·42
November	49·85	50·50	50·17	47·59	48·26	47·92	45·40	46·00	45·70	45·57	45·87	45·72	4·28	4·63	4·45
December	41·58	41·28	41·43	39·61	39·23	39·42	37·00	36·80	36·90	37·18	36·71	36·94	4·40	4·57	4·49
Means	50·43	51·94	51·20	51·53	52·04	51·78	48·73	48·62	48·66	43·93	44·12	44·03	6·50	7·82	7·17
				Mean of observed dew-point					48·56	From May ...		48·56			

Hygrometrical state of the Atmosphere at Whitehaven, in the year 1848.

1848.	Dry bulb.			Wet bulb.			Dew-point.								
							Deduced.			Observed.					
													Compt. of Dew-point.		
	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.
January	35°·50	36°·58	36°·04	33°·94	34°·68	34°·31	31°·50	31°·75	31°·62	31°·62	31°·85	31°·73	3°·88	4°·73	4°·30
February.........	43·16	44·06	43·61	41·85	42·60	42·22	40·12	40·83	40·47	40·05	40·72	40·38	3·11	3·34	3·22
March............	43·82	45·46	44·64	41·69	42·68	42·18	39·20	39·50	39·35	39·38	39·26	39·32	4·44	6·20	5·32
April	48·86	51·07	49·96	45·03	46·90	45·96	40·75	42·70	41·72	40·91	42·41	41·66	7·95	8·66	8·40
May	57·57	59·77	58·67	52·80	54·29	53·54	49·45	50·30	49·87	49·40	50·29	49·84	8·17	9·48	8·82
June	60·25	61·21	60·73	55·37	55·51	55·44	52·01	51·48	51·74	52·18	51·29	51·73	8·07	9·92	8·99
July	61·88	64·13	63·00	57·38	58·72	58·05	54·25	55·02	54·63	54·28	55·34	54·81	7·60	8·79	8·19
August	59·22	61·50	60·36	54·32	55·69	55·00	50·87	51·64	51·25	50·80	51·32	51·06	8·42	10·18	9·30
September	58·37	59·91	59·14	54·46	55·32	54·89	51·72	52·11	51·91	51·45	51·64	51·54	6·92	8·27	7·59
October	51·21	51·78	51·49	48·59	48·56	48·57	46·00	45·30	45·65	45·85	45·35	45·60	5·36	6·43	5·89
November	43·99	44·76	44·37	42·17	42·57	42·37	40·04	40·07	40·05	40·14	39·95	40·04	3·85	4·81	4·33
December	42·92	42·89	42·90	41·10	41·24	41·17	38·92	39·14	39·03	39·08	38·35	38·71	3·84	4·54	4·19
Means......... ..	50·56	51·93	51·24	47·39	48·23	47·81	44·57	44·98	44·77	44·59	44·81	44·70	5·97	7·11	6·54

In eight months of the year 1847, the difference between the observed and the deduced dew-point is 0°·10, and in 1848 it is but 0°·07, the mean of the two periods comprising 1220 observations, amounting to the comparatively evanescent fraction of $\frac{8}{100}$ths of a degree; and, had the instruments been *absolutely* perfect, doubtless the accordance between the two dew-points would have been still more obvious. Hence the results show, in a striking manner, the extreme accuracy of Mr. GLAISHER's Tables, and add additional testimony to the value of the Greenwich hygrometrical observations, and the resulting formula on which those Tables are founded. Being strongly impressed with the utility and importance of these tables, I am induced to give my own experimental evidence in their favour, which (coming from a wholly disinterested party) may perhaps be entitled to some weight; and, in the hope of giving them greater publicity, and of bringing them into that general use which they so well merit, I beg to lay that evidence before the Royal Society.

By means of the tables founded on the Greenwich hygrometrical observations, the combination of the dry- and wet-bulb thermometers is converted into a very delicate scientific instrument, possessing many advantages over that of DANIELL, not the least of which is, that its readings may be depended upon, even in the hands of the most inexperienced and uneducated person. Thus, observations on the hygrometrical state of the atmosphere may be obtained on mountains, at great heights above the sea, on the sea itself, in mines, and various other inconvenient localities, by those whose occupations or callings lead them to spend a considerable portion of their time in such situations. In this way illiterate persons may become truly valuable assistants to the meteorologist in his researches, and the observations secured by the shepherd, the miner, and the mariner may afterwards be turned to good account by the philosopher in his closet.

It is however necessary that the thermometers used for this purpose should be essentially good, and, if possible, that their readings should agree with each other,

and with a standard instrument. But as perfect thermometers are very difficult to obtain, most of such instruments will differ from a standard at one point or other of the scale. They should therefore be carefully compared, and the errors allowed for, either at each reading, at the end of every month, or at some stated period. The goodness of the instruments, or the application of the corrections, is the more essential, as any error in either or both the thermometers is considerably increased in the resulting temperature of the dew-point. The bulbs should be carried fully an inch below the metal or wood scale. The wet bulb should be covered with book-muslin, and the best conductor of the water from the cistern to the bulb is a piece of cotton lamp-wick, which must be changed as circumstances require, as in time it is apt to lose its capillary action. In winter, the water in the vessel will frequently be frozen, and the wet bulb quite dry: in this case the bulb must be moistened, when a coating of ice will form on it, from which evaporation will take place: an hour or more will however sometimes elapse before the temperature of the moist bulb falls below that of the dry.

It is well known that evaporation goes on freely from the surface of frozen water, even when the whole mass is converted into a solid block of ice. From the 11th to the 16th of December 1846, during which a brisk breeze prevailed, the loss from my evaporation gauge was 0·450 inch, or ·075 per diem, the average of the month being but ·033 per diem. In twelve days of frost in February, 1847, the evaporation from the ice was ·552, or ·046 per day, the average daily quantity for the month being ·030. During ten days of keen frost, between the 20th and 30th of January, 1848, the ice had parted with 0·324 inch, or ·032 per diem, the average daily loss for the month being only ·024. For five days of December 1848, the loss was ·037 per diem, the daily average for the month being ·032; and from the 1st to the 8th of January, 1849, the depth evaporated was equivalent to ·017 per diem, the average daily loss during the month being ·029 inch. Hence it appears, that notwithstanding the large amount of heat required, not only to liquify but to vaporize frozen water, the vapour thrown off by ice in an invisible form exceeds in amount the average daily evaporation from an equal surface of water in the winter season. This apparently anomalous circumstance probably arises from the extreme dryness of the atmosphere, and its consequently increased capacity for vapour in severe frosts, whereas at other times during the winter the air is very moist near the sea, being generally not more than 2° or 3° above the point of saturation.

The subject of evaporation has been very little investigated or treated of since the publication of Mr. HOWARD's 'Climate of London' in the year 1818, and having paid considerable attention to this department of meteorology for several years past, I may perhaps be excused (though not directly connected with the issue of this paper) from briefly giving the results of my own investigations, obtained at nearly the opposite point of the kingdom. Evaporation is scarcely ever *entirely* suspended, either during the heaviest rains, or when the air is completely saturated with vapour; at

least, I have not met with more than two or three instances in which some daily loss was not appreciable to a finely graduated metre. In severe nights, the depth evaporated in twenty-four hours will sometimes, though very rarely, reach $\frac{4}{10}$ths of an inch. On the 22nd of May, 1844, 0·430 was measured, and on a freezing mixture being applied to DANIELL's hygrometer, the dew-point was found to be 24° below the temperature of the air, which was 63°. The evaporation for the month was 6·280 inches, with only a quarter of an inch of rain.

Amount of Evaporation at Whitehaven, Cumberland, in the six years ending with 1848.

Month.	1843.	1844.	1845.	1846.	1847.	1848.
	in.	in.	in.	in.	in.	in.
January	·785	·940	·935	1·015	·860	·743
February ...	1·178	1·190	·905	1·335	·843	·792
March.........	1·620	1·835	1·862	2·085	1·821	1·397
April	1·718	2·610	3·400	2·575	2·181	2·728
May	3·045	6·280	3·645	4·375	2·950	4·580
June	4·690	3·820	3·760	6·645	4·506	3·749
July............	3·125	4·495	5·455	3·450	4·726	3·935
August	3·305	2·520	3·250	3·875	3·751	3·686
September ...	3·745	3·405	3·225	2·980	2·793	2·896
October	1·940	2·270	2·360	1·780	1·688	1·549
November ...	1·030	1·554	1·760	1·360	1·107	1·129
December ...	·800	·800	1·875	1·025	1·005	1·019
Inches.........	26·981	31·719	32·432	32·500	28·231	28·203*

The mean amount of evaporation for the six years is 30·011 inches, and the average quantity of rain for the same period is 45·255 inches, so that the depth of the water precipitated exceeds that taken up by evaporation at the coast, in the latitude of $54\frac{1}{2}°$, by 15·244 inches.

The evaporation gauge with which the above experiments were made, is a copper vessel 8 inches in diameter, and rather more than an inch and a half in depth. Half an inch of water is accurately measured and poured into the dish, and the daily loss ascertained each morning at 9 o'clock, by means of a carefully graduated tube reading to the thousandth part of an inch†.

The evaporation dish receives a fair proportion of wind and sun, and is always exposed in the open air during the day, except when rain is falling. At night, and in wet weather, it is placed under a capacious shed, 9 feet in height, and open in front. Thus, it is conceived, that the evaporating surface is freely acted upon by all the circumstances concerned in promoting this natural process.

Mr. HOWARD found the evaporation near the surface of the ground in the neighbourhood of London to be about 20 inches, or 5 inches under the average fall of

* Evaporation in 1849, 28·699 inches.

† Till the close of 1846, the dish was placed on a stool, 8 inches above the ground; since that period it has been placed on a stand 4 feet 4 inches in height, and just large enough to hold it.

rain; but the gauge was constantly under cover, and consequently but little exposed to the direct rays of the sun, which will account for the great difference between the results at Whitehaven and the metropolis. Had the gauges been in all respects similarly circumstanced, the evaporation at London, from its higher mean temperature, would probably have been found to exceed the amount registered in the higher latitude.

The Observatory, Whitehaven,
October 20th, 1849.